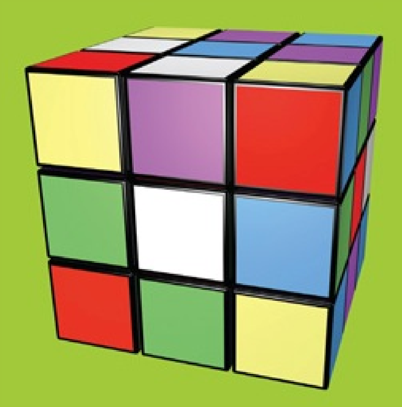

Simulation of wave propagation problems for automated non-destructive characterization of material parameters and defects

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Abstract

The majority of Non-destructive testing (NDT) techniques is based on the emission and reception of acoustic, electromagnetic or elastic waves. During the wave propagation, information about the sample's material properties and about the position, shape and orientation of internal defects is gathered in the reflections/transmissions and in the spectral content, including higher harmonics, of the measured signal. The decoding process to extract this information can however be extremely tedious. In order to automate the process, the characterization of the defect can be formulated as an inverse problem related to the forward wave propagation problem. The properties, described by control parameters, of a trial defect need to be optimized such that the calculated output signals match the measured ones. This problem is generally considered as unmanageably complicated. Instead, in the NDT community, there is a large, accumulated know-how on the semi-heuristic interpretation of tomographic images. Both approaches have their limitations in accurately finding the desired properties of defects. Hence we aim to develop hybrid methods. In our work, we observe recent progress in scientific computing which motivates to address the inverse problem directly by using an adjoint-based optimization package (dolfin-adjoint [1]) and the discontinuous Galerkin finite element method (implemented using FEniCS [2]).

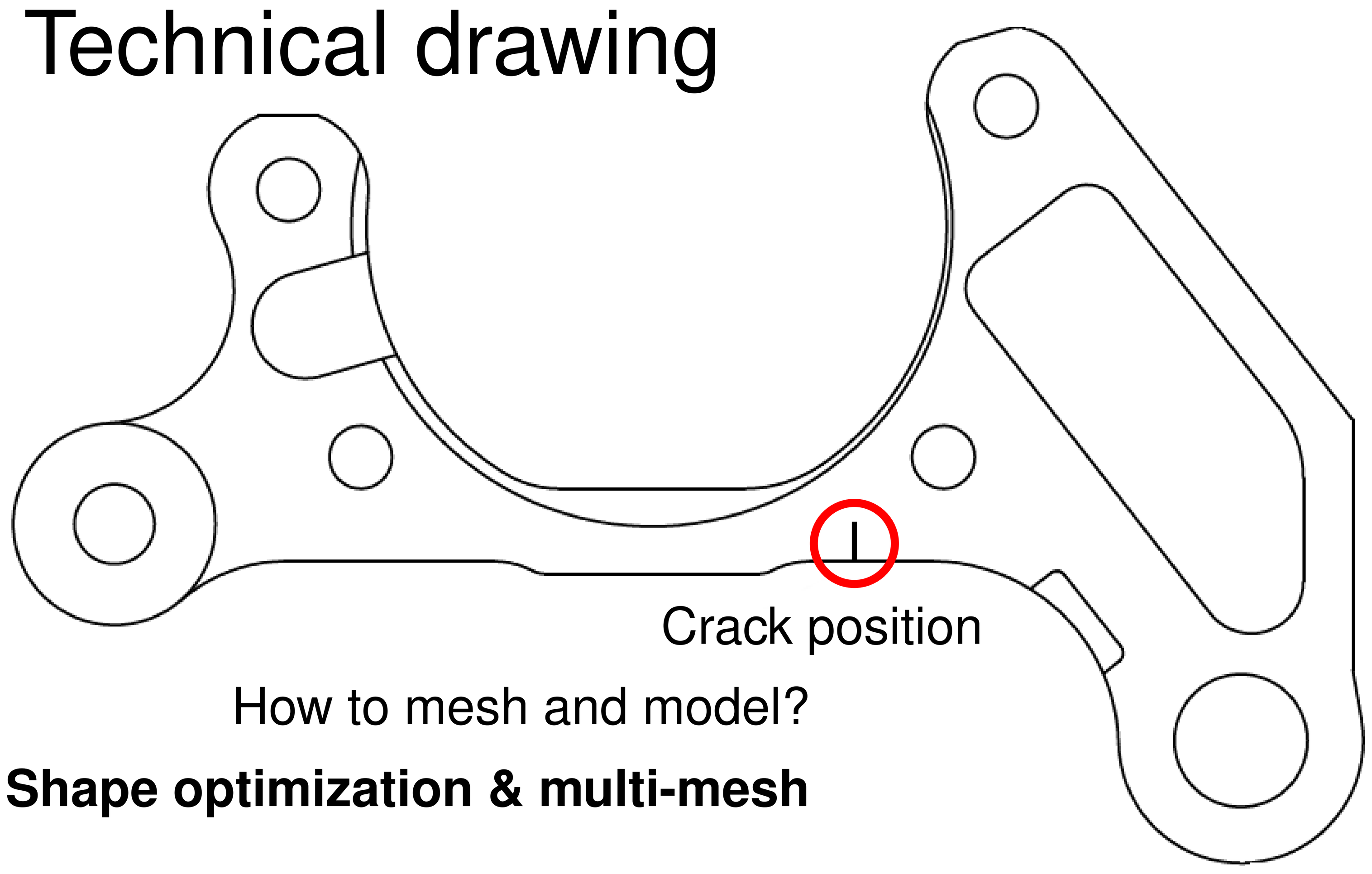
Non-destructive testing

Physical set-up

What are the material parameters?
Are there defects? Where?

Topology optimization

Technical drawing



How to mesh and model?

Shape optimization & multi-mesh

FEniCS PROJECT

The inverse problem can be expressed as

$$\min \|\boldsymbol{q}(t) - \boldsymbol{q}_{\text{measured}}(t)\|$$

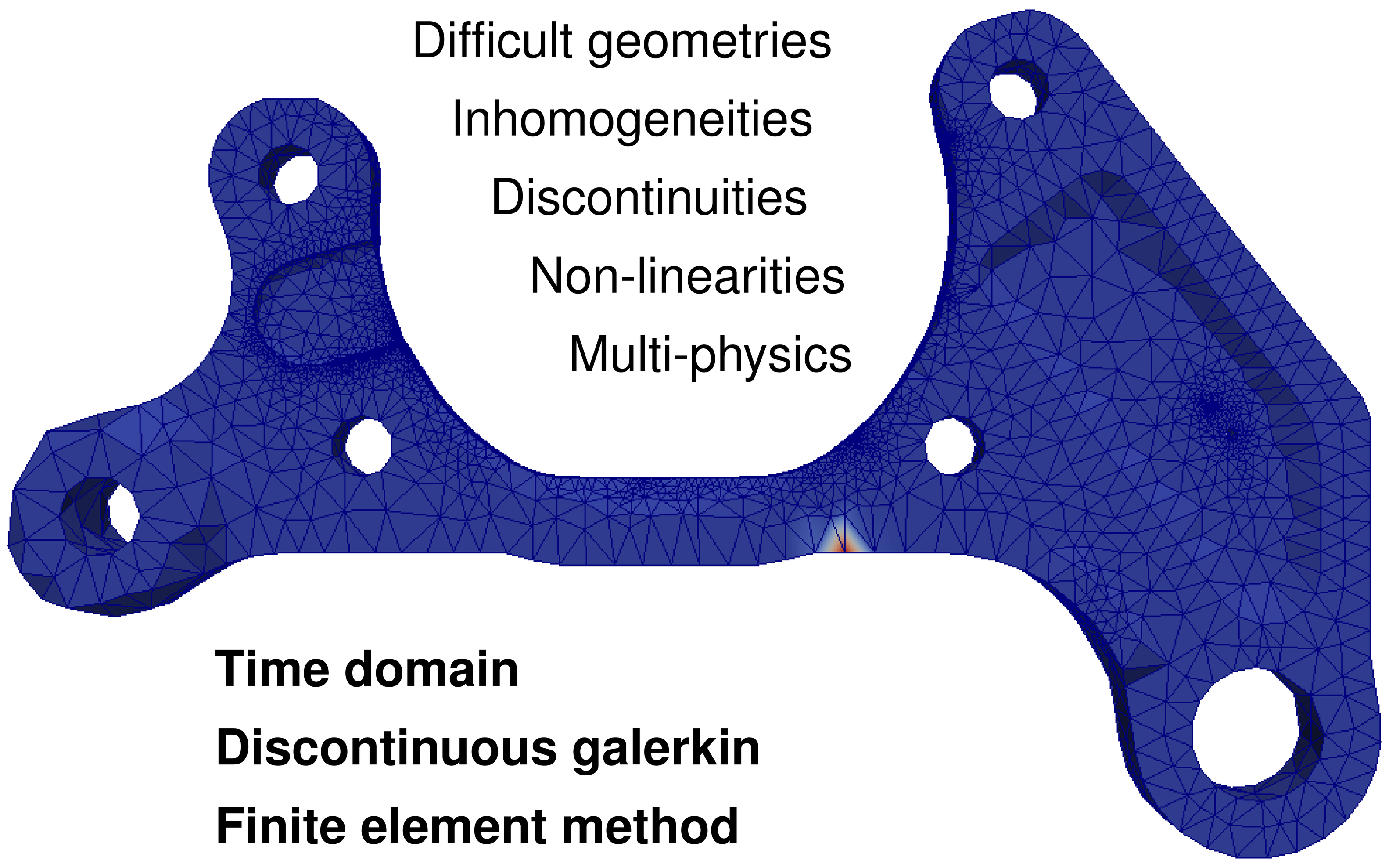
subjected to

$$\dot{\boldsymbol{q}} + \nabla \cdot \boldsymbol{F}(\boldsymbol{q}) = \boldsymbol{f}$$

dolfin-adjoint

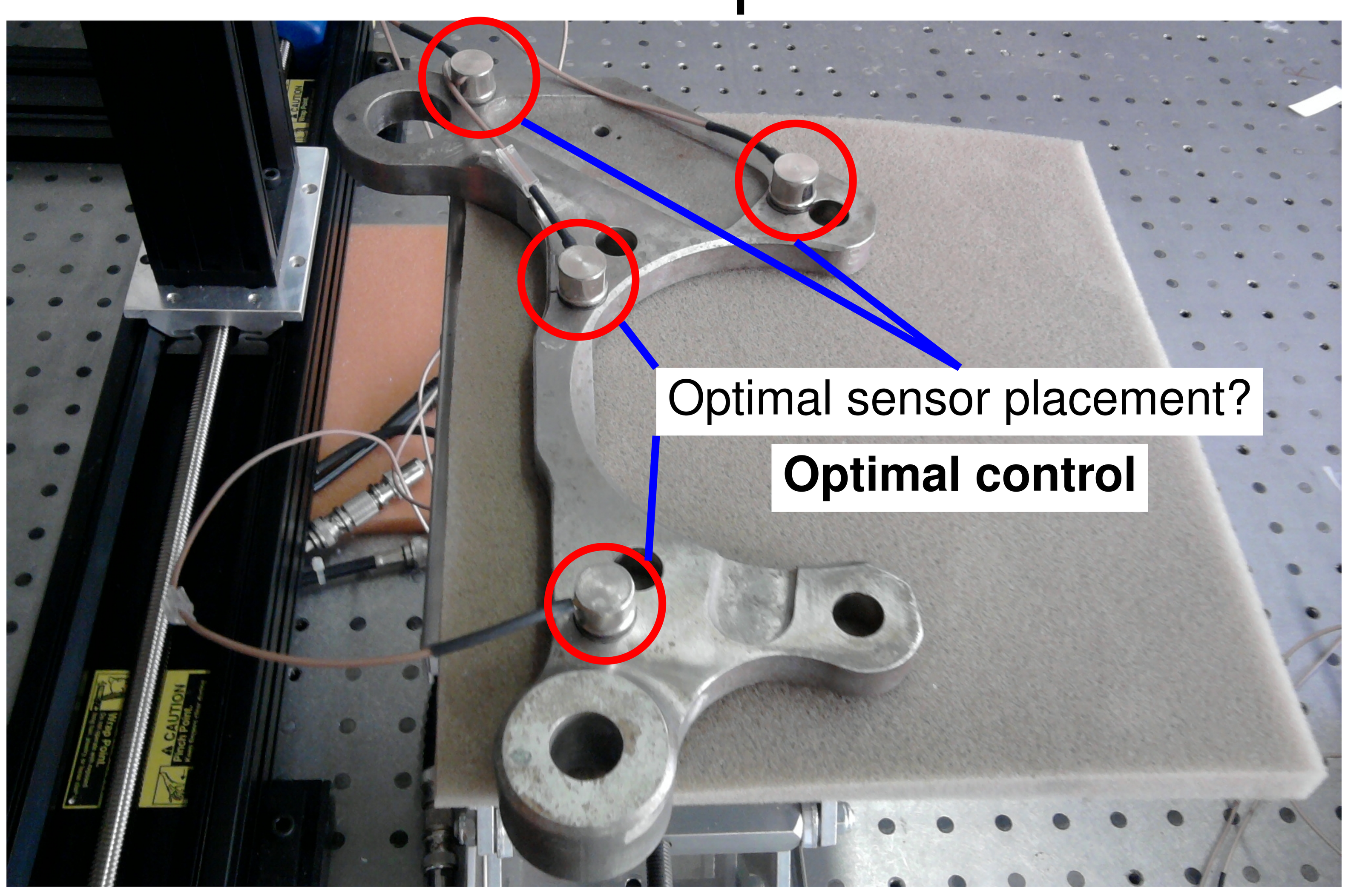
Numerical simulation

Difficult geometries
Inhomogeneities
Discontinuities
Non-linearities
Multi-physics



Time domain
Discontinuous galerkin
Finite element method

Measurement set-up



[1] Patrick E. Farrell, David A. Ham, Simon W. Funke and Marie E. Rognes, *Automated derivation of the adjoint of high-level transient finite element programs*, SIAM Journal on Scientific Computing 35.4, pp. C369-C393, 2013.

[2] A. Logg, K.-A. Mardal, G. N. Wells, *Automated Solution of Differential Equations by the Finite Element Method*, Lecture Notes in Computational Science and Engineering , 84, Springer Berlin Heidelberg, 2012.